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Statement of inventorship and of right to grant of a patent

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1.	Your reference	102318/DJW
2.	Patent application number *(if you know it)*	**0020624.3** 21 AUG 2000
3.	Full name of the or of each applicant	Element 14, Inc.
4.	Title of the invention	MULTI-BAND DMT RECEIVER
5.	State how the applicant*(s)* derived the right from the inventor*(s)* to be granted a patent By virtue of a contract of employment.	
6.	How many, if any, additional Patents Forms 7/77 are attached to this form? *(see note (c))*	
7.		I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent application relates to. Signature Date 21 August 2000
8.	Name and daytime telephone number of person to contact in the United Kingdom	David J. Williams – 020 7831 7929

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Patents ADP number *(if you know it):* 7945799001

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2.	Patent application num *(The Patent Office will fill ir*	0020624.3
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Element 14, Inc. Suite 210, The Quorum Barnwell Road Cambridge CB5 8RE
	Patents ADP number *(if you know it)*	7797392002
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	MULTI-BAND DMT RECEIVER
5.	Name of your agent *(if you have one)*	Page White & Farrer
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	54 Doughty Street London WC1N 2LS
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MULTI-BAND DMT RECEIVER

The present invention relates to the demodulation of a multi-band DMT signal in a receiver, and particularly but not exclusively to the demodulation of a multi-band DMT signal in the transceiver of a modem.

Referring to Figure 1 there is shown an example of a multi-band signal transmitted in the upstream (or uplink) of a communications system. In this example it is assumed that the multi-band signal comprises two bands. As shown in Figure 1, a first band is defined between the frequencies f_1 and f_2, and a second band is defined between the frequencies f_3 and f_4. A downstream frequency band may be provided between the frequencies f_2 and f_3, and a further downstream frequency band may be provided beyond the frequency f_4.

Techniques for transmitting and receiving such multi-band signals are well known. For example, in modem technology a multi-carrier signal having multiple frequency bands is transmitted.

At the receive side, such multi-band signals require a large amount of processing. The processing speed of the receiver is determined by the highest frequency of the multi-band signal. That is, the receiver has to operate at a speed such that the received signals having the highest frequencies can be processed within system constraints.

It is an object of the present invention to provide an improved multi-band DMT receiver in which an improved processing of the received signal is achieved.

According to a first aspect of the invention there is provided a receiver for receiving a multi-band signal modulated using an inverse discrete Fourier transform, comprising: a plurality of demodulators, each demodulator for demodulating a respective one of the plurality of bands in a multi-band signal

wherein each demodulator includes a discrete Fourier transform. Thus, the processing of the multi-band signal is spread amongst more than one demodulator, so that each discrete Fourier transform (DFT) can be optimised for a particular frequency band.

The process speed of each demodulator may then be determined by the respective frequency band. That is, if a particular demodulator processes a frequency band having a high frequency, then a corresponding high sampling speed is required in the respective demodulator. A lower frequency band requires a lower sampling speed in the respective demodulator. Thus the process speed of each demodulator is preferably determined by the respective frequency band of the signal processed therein.

Each demodulator may further include an equaliser connected to the output of the discrete Fourier transform. Each demodulator may further include a filter for filtering the received signal prior to the discrete Fourier transform.

The multi-band signal may be generated by nulling selected tones in the modulator. In addition to. Or alternatively, the multi-band signal may be generated by filtering the output of the modulator.

The receiver may comprise part of a transceiver. In such a transceiver, each demodulator may further include an echo canceller for removing an echo associated with the signal in a transmitter of the transceiver from the received signal. The echo canceller may be connected to remove the echo at the inputs of the discrete Fourier transform. Each echo canceller may comprise an adaptive filter.

In a second aspect the present invention provides a method of demodulating a multi-band signal modulated using an inverse discrete Fourier transform, comprising the step of: providing a demodulator for each respective band in a

multi-band signal, wherein each demodulator performs .a discrete Fourier transform.

Each demodulator may further comprise an equalisation step. Each demodulator may further filter the received signal prior to the discrete Fourier transform.

The multi-band signal may be generated by nulling selected tones in the modulator. In addition to. Or alternatively, the multi-band signal may be generated by filtering the output of the modulator.

The demodulating step may be carried out in a transceiver. In a transceiver, each demodulator further performs an echo cancellation step to remove an echo associated with a signal in a transmitter of the transceiver from the received signal.

The invention will now be described with regard to an illustrative example with reference to the accompanying drawings in which:

Figure 1 illustrates the frequency spread of a two-band signal in one direction;

Figure 2 illustrates a multi-band transmission system in accordance with a preferred implementation of the present invention;

Figures 3(a) and 3(b) illustrate alternative implementations of the splitter of the receiver of Figure 2; and

Figure 4 illustrates a DMT receiver in accordance with a preferred embodiment of the present invention.

In the following illustrative example the present invention will be described by way of reference to a particular implementation in which a modem transceiver transmits a DMT (discrete multi-tone) signal, and the DMT signal is received by a transceiver of another modem.

Referring to Figure 2 there is illustrated a first modem 214 and a second modem 218. For the purposes of this example it is assumed that the first modem 214 transmits a multi-band signal to the second modem 218. Therefore only the transmitter portion of a transceiver of the first modem 214 is discussed in detail and only a receiver portion of the transceiver of the second modem 218 is discussed in detail.

In accordance with known techniques, the transmitter of the first modem 214 includes an inverse discrete Fourier transform 204, a digital to analogue converter 218, and a hybrid 212. As the transmitter described herein is a DMT transmitter, there is also provided a cyclic prefix (CP) insertion block 205. The inverse discrete Fourier transform (IDFT) block 204 receives on a plurality of signal lines 202 data to be encoded for transmission. The thus encoded data is output by the IDFT block 204 in series on line 207. The operation of the IDFT block 204 is outside the scope of the present invention, and its implementation will be well know to one skilled in the art. The CP insertion block inserts a 32 sample guard band in front of the 512 sample symbols generated by the IDFT. As known in the art, the CP insertion includes repeating the last 32 sample of the 512 sample symbol to thereby generate a 544 sample symbol.

Modulated and encoded data output by the CP insertion block 205 on line 206 is converted into an analogue signal on line 210 by the digital to analogue converter 208, and the hybrid 212 transmits the analogue signal on a channel 216.

The plurality of signals on line 202 are provided by a transmitter which generates a discrete multi-tone (DMT) signal with N/2 tones with a tone spacing of ΔF. Consequently the IDFT generates a transform having N points. Thus, the bands of the multi-band signal are generated by nulling certain tones at the input to the IDFT204. In addition, the nulling may be assisted by appropriate filters at the output of the IDFT 204.

After the CP insertion the symbols may be optionally windowed. Windowing shapes the symbols before transmission in order to reduce the leakage in the adjacent band. Windowing multiplies a certain number of samples at the beginning and end of a symbol by a weighting function. Usually the number of windowed samples is smaller than the length of the guard-band. The shaping of two contiguous symbols could overlap. This windowing principle is used, for example, in the VDSL multi-carrier standard.

The analogue signal on a channel 216 is received by the transceiver of the modem 218. The transceiver of the modem 218 includes a hybrid 220 and a splitter 221. In accordance with the present invention, the receiver of the modem 218 in addition comprises a plurality, in this example two, of receivers 224a and 224b. In this example it is assumed that the signal transmitted by the transmitter of the first modem 214 corresponds to the signal of Figure 1 and includes two frequency bands. In general the signal will include a plurality n of frequency bands, and the receiver of the modem 218 will be provided with a plurality n of the receivers 224.

In addition the modem 218 includes transmitter circuitry 223 which provides a signal to be transmitted to the hybrid 220 on line 225.

Each of the demodulators 224a and 224b is constructed identically, and the various components therein have identical reference numerals except for the designation of a or b. Thus the receiver 224a will be described hereinafter, and it will be understood that demodulator 224b is constructed in exactly the same manner.

Before discussing the receivers 224, reference is made to Figures 3(a) and 3(b) which illustrate in block diagram form respective digital and analogue implementations of the splitter 221.

In a digital implementation, the signal on line 222 is converted into an analogue signal on line 316 by an analogue to digital converter 300, and then presented to respective low and high pass filters 302a and 302b. The output of the low pass filter 302a on line 314a is processed by block 304, which in turn generates a signal to the first receiver 224a. The block 304 is a downsampler. The principle of this device is to reduce the sampling speed by a certain factor. For example a downsampler by 2 divides the sampling speed by 2 between its input and output. The division is done by taking one sample every two samples. For the input sequence 1 2 3 4 5 6 7 8 9 10 ... to the downsampler, the output sequence is 1 3 5 7 9 11 ...The output of the high pass filter 302b on line 314b forms the signal on line 223b to the second receiver.

In an analogue implementation, the signal on line 222 is provided to respective low and high pass filters 310a and 310b. The outputs of these filters on lines 315a and 316b are converted into digital form by analogue to digital converters 312a and 312b, which generate the signals 223a and 223b to the receivers 224a and 224b.

At the output of the splitter both streams are sampled at their respective Nyquist frequency even if the ADC is running at the Nyquist frequency of the highest band.

Each filter stream in the digital implementation of Figure 3(a), and each stream in the analogue implementation of Figure 3(b), can be processed with a DFT of Fs,k/ΔF points. This is because each stream need only process the points for its particular band. Each stream is sampled at a frequency Fs,k, where Fs,k is at least two times the maximum frequency of the band.

The receiver 224a comprises a time equaliser 234a, a subtractor 238a, a cyclic prefix removal block 239a, a discrete Fourier transform (FFT) 244a, a frequency equaliser 248a, and an echo canceller 242a. In this preferred embodiment the echo canceller 242a is comprised of an adaptive filter.

The time equaliser 234a is preferably a finite impulse response (FIR) filter.

The digitised version of the received signal for the particular frequency band is provided on line 223a by a respective one of either the digital or analogue splitters of Figures 3(a) and 3(b). In accordance with conventional techniques, the echo canceller 242a preferably comprises an adaptive filter and receives a representation on line 225 of the signal in the transceiver for the modem 218 which is being transmitted by the hybrid 220. The echo canceller 242a then provides an estimate of the echo associated with this transmitted signal on line 262a. The subtractor 238a subtracts the estimate of the echo on line 262a from the time equalised received signal on line 236a, to generate an estimate of the received signal on line 240a. As is known in the art, the signal on line 240a is used to control the echo canceller 242a to adjust the estimate of the echo on line 262a.

The cyclic prefix (CP) removal block 239a operates in the reverse manner to the cyclic prefix (CP) insertion block 205 to remove the 32 samples of the cyclic prefix, forming a guard band, from the 544 samples of the received symbol. When windowing is applied at the transmitter, the cyclic removal process is identical.

The estimate of the received signal on line 241a, after the cyclic prefix removal block, is then input to the discrete Fourier transform 244a. The outputs of the discrete Fourier transform on line 246a are provided to the frequency equaliser 248a for equalisation. The thus equalised signals provided on line 250a are provided for further processing in the receiver of the modem 218. The CP

removal block 239a, the discrete Fourier transform 244a and the equaliser 248a each receive a clocked signal on line 264a for controlling the speed of the operations performed therein.

The receiver 224b is similarly constructed.

Thus in accordance with the invention the demodulation of the different bands of the multi-band signal are processed independently such that each modulator can be optimised to perform for that particular frequency band. In the present example it is shown that the receiver 224a demodulates the lower frequency band of Figure 1, and the receiver 224b demoduiates the higher frequency band of Figure 1. In the example that the highest frequency within the lower frequency band is a frequency of 200 kHz, then the sampling speed of the demodulator 224a must be at least 400 kHz. If, for example, the highest frequency within the higher frequency band is 2 MHz, then the sampling speed must be at least 4 MHz. Thus lower frequencies can be processed at a lower sampling speed.

This contrasts with prior art arrangements, where even low frequency received signals have to be sampled at a sampling speed dictated by the highest possible frequency of the multi-band signal. Therefore in prior art arrangements the 200 kHz signal is processed at a sampling speed of 4 MHz. This is particularly advantageous for the implementation of the echo canceller 242. For the low frequency bands the echo canceller need only be processed at the low sampling speed (that is at the Nyquist speed), rather than always having to be processed at the speed determined by the Nyquist speed of the highest frequency signal.

The main advantage of the invention is that the processing of the lower band, or bands, can be performed at a lower speed. Primarily this means that the time equaliser 234 and the echo canceller 242 consume less CPU processing.

Each of the filters 302 or 310 implement the necessary processing to select the frequency band for the respective receiver.

The above example presents the invention with particular reference to receipt of a discrete multi-tone (DMT) signal. The invention may be advantageously applied in environments such as asymmetric digital subscriber line (ADSL) technology, or very-high-data-rate digital subscriber line (VDSL) technology for example.

CLAIMS:

1. A receiver for receiving a multi-band signal modulated using an inverse discrete Fourier transform, comprising:

a plurality of demodulators, each demodulator for demodulating a respective one of a plurality of bands in the multi-band signal, wherein each demodulator includes a discrete Fourier transform.

2. The receiver of claim 1 wherein the process speed of each demodulator is determined by the respective frequency band.

3. The receiver of claim 1 or claim 3 wherein each demodulator further includes an equaliser connected to the output of the discrete Fourier transform.

4. The receiver of any one of claims 1 to 3 wherein each demodulator further includes a filter for filtering the received signal prior to the discrete Fourier transform.

5. A transceiver including a receiver according to any one of claims 1 to 4.

6. The transceiver of claim 5 in which each demodulator includes an echo canceller for removing an echo associated with a signal in a transmitter of the transceiver from the received signal.

7. The transceiver of claim 6 in which the echo canceller is connected to remove the echo at the input to the discrete Fourier transform.

9. The transceiver of claim 6 or claim 7 in which each echo canceller comprises an adaptive filter.

10. The receiver of any one of claims 1 to 8 in which the multi-band signal is generated by nulling selected tones in the modulator.

11. The receiver of any one of claims 1 to 9 in which the multi-band signal is generated by filtering the output of the modulator.

12. A method of demodulating a multi-band signal modulated using an inverse discrete Fourier transform comprising the step of:

providing a demodulator for each respective band of the multi-band signal wherein each demodulator performs a discrete Fourier transform.

13. The method of claim 12 wherein each demodulator further comprises an equalisation step.

14. The method of claim 12 or claim 13 wherein each demodulator filters the received signal prior to the discrete Fourier transform.

15. The method of any one of claims 12 to 14 in which the demodulating step is carried out in a transceiver.

16. The method of claim 15 in which each demodulator further performs an echo cancellation step to remove an echo associated with the signal in a transmitter of the transceiver from the received signal.

17. The method of any one of claims 12 to 16 in which the multi-band signal is generated by nulling selected tones in the modulator.

18. The method of any one of claims 12 to 17 in which the multi-band signal is generated by filtering the output of the modulator.

ABSTRACT

MULTI-BAND RECEIVER

There is disclosed a receiver for receiving a multi-band DMT signal. The receiver includes a plurality of demodulators, each demodulator having a discrete Fourier transform and being provided to demodulate a respective one of a plurality of bands in the multi-band signal, the multi-band signal being modulated in an inverse discrete Fourier transform. A method of demodulating a multi-band signal is also provided.

[Figure 2]

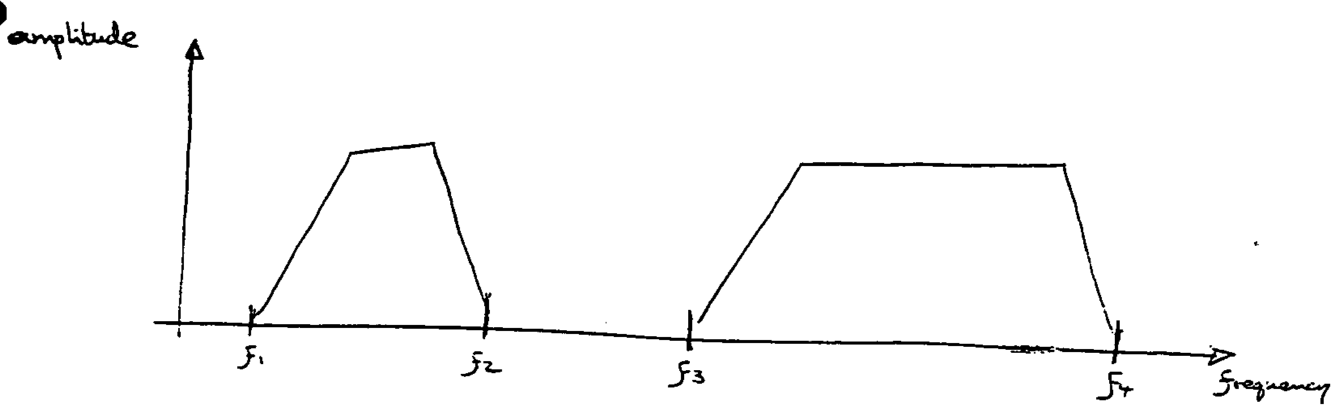
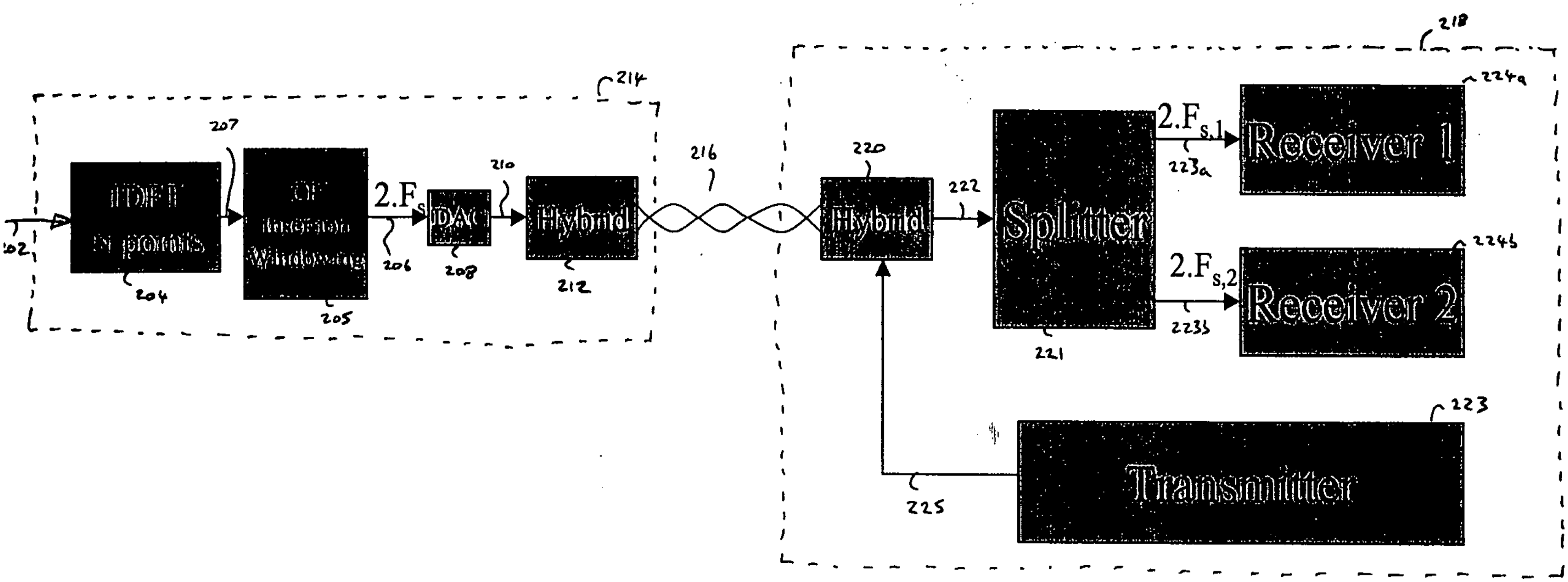


FIGURE 1


202
IDFT
N points
204
207
CP
Insertion
Windowing
205
2.Fs
206
DAC
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Hybrid
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223a
2.Fs,2
223b
Receiver 1
224a
Receiver 2
224b
Transmitter
223
225

FIGURE 2

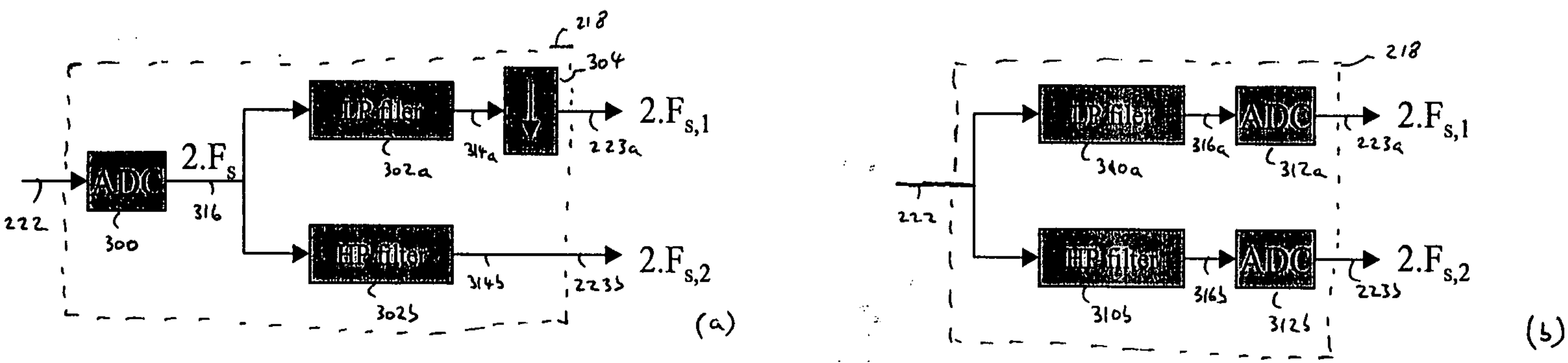

FIGURE 3

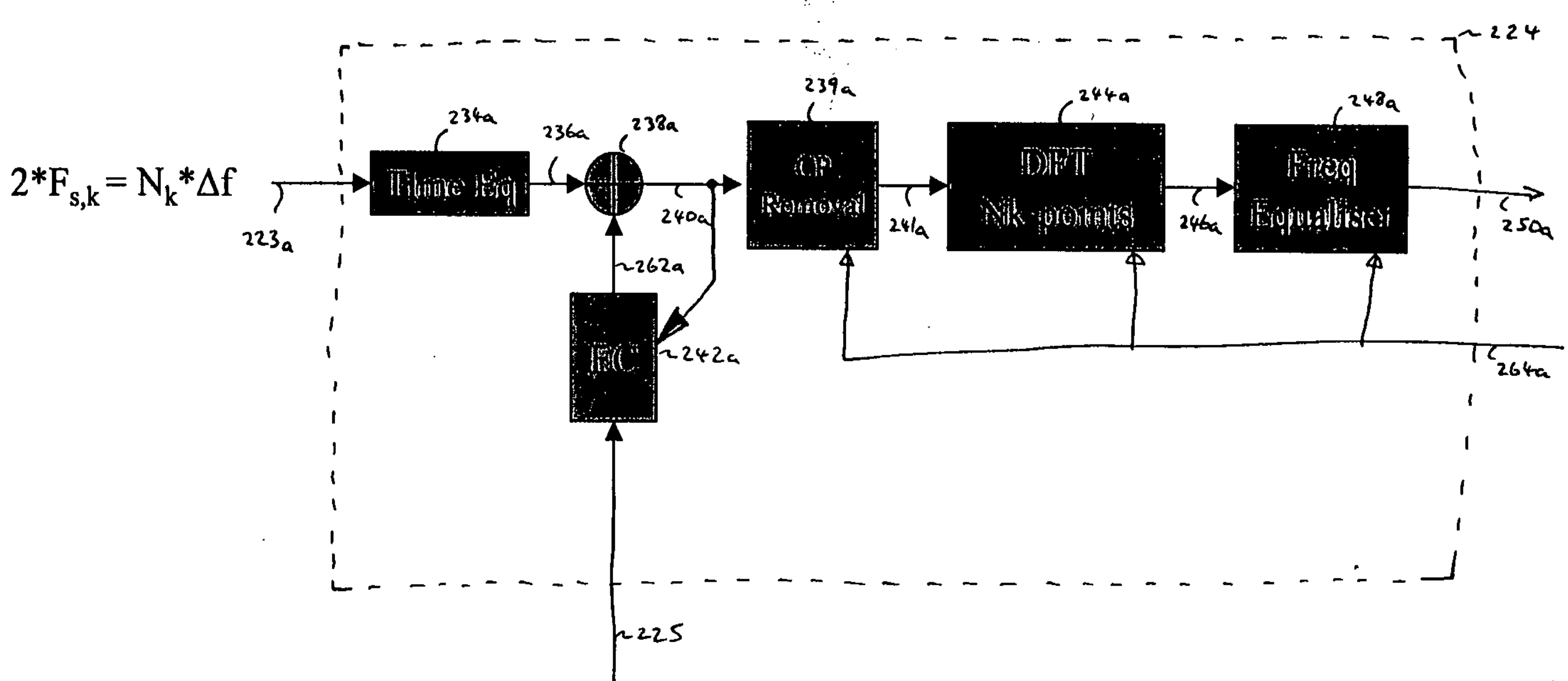

FIGURE 4